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Goto et al.

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(54) **GAME CONTROLLER WITH PULSE WIDTH MODULATION POSITION DETECTION**

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A63F 13/20	(2014.01)
A63F 13/213	(2014.01)

(52) **U.S. Cl.**

CPC ***A63F 13/06*** (2013.01); *A63F 13/213* (2014.09); *A63F 2300/1006* (2013.01); *A63F 2300/1043* (2013.01); *A63F 2300/1093* (2013.01); *A63F 2300/301* (2013.01); *A63F 2300/6045* (2013.01)

(58) **Field of Classification Search**

CPC A63F 2300/6045; A63F 2300/1087; A63F 2300/1093; A03F 13/213

USPC 463/37, 39

See application file for complete search history.

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(57) **ABSTRACT**

A game controller includes a plurality of LEDs formed on the rear of a case. The plurality of LEDs are arranged two-dimensionally in its layout area. The game controller has a plurality of PWM control units which are provided inside the case and control the lighting of the plurality of LEDs, respectively. The PWM control units control the lighting of the LEDs based on a control signal from a game apparatus. The game apparatus acquires a captured image of the game controller, and acquires the position of the game controller in the captured image based on the positions of the LEDs in the captured image.

3 Claims, 13 Drawing Sheets

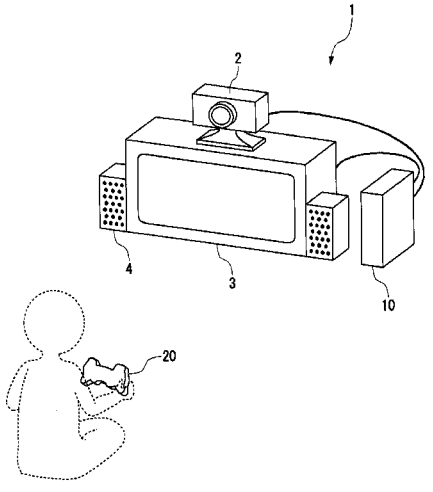

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FIG.1

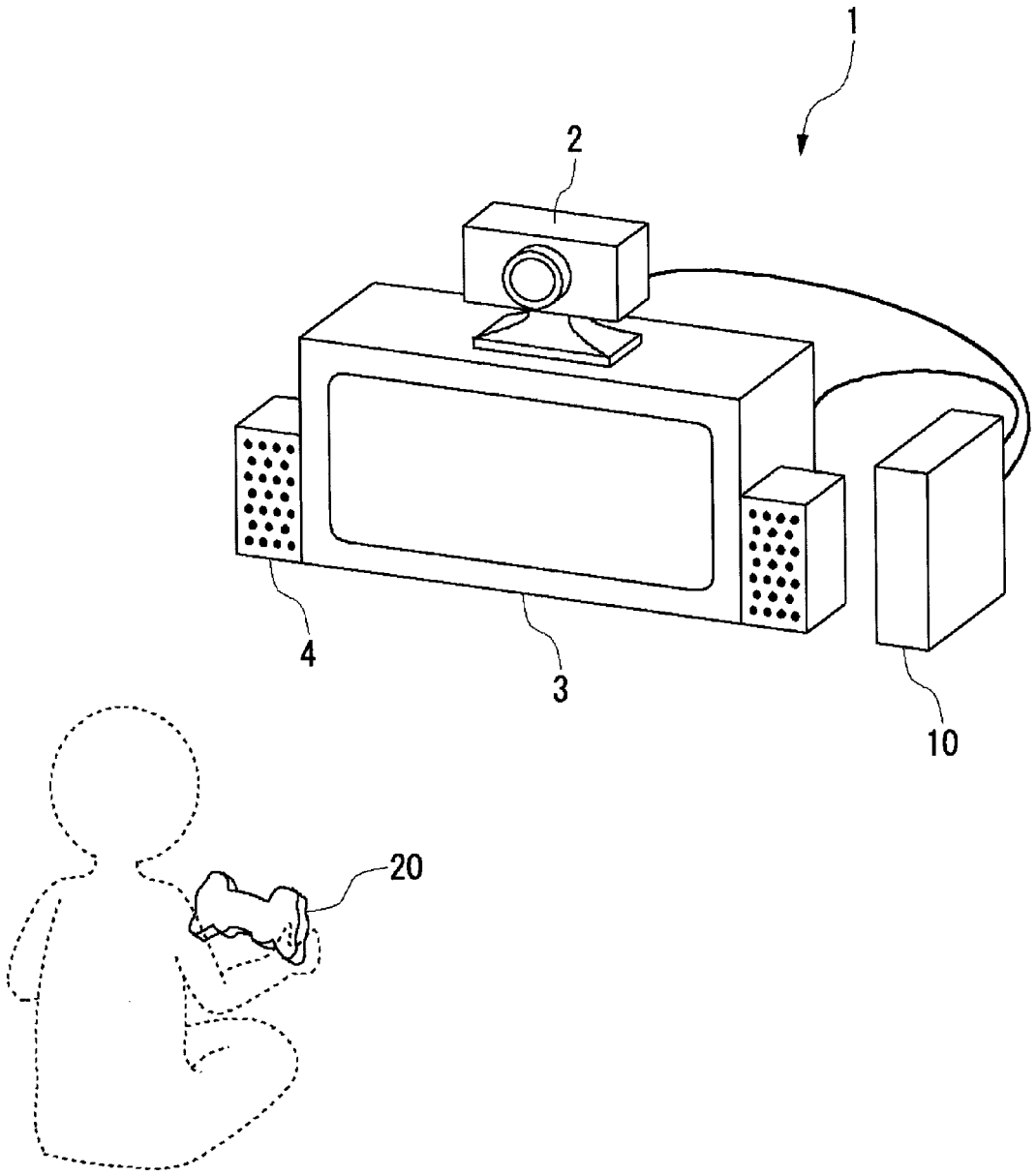


FIG.2

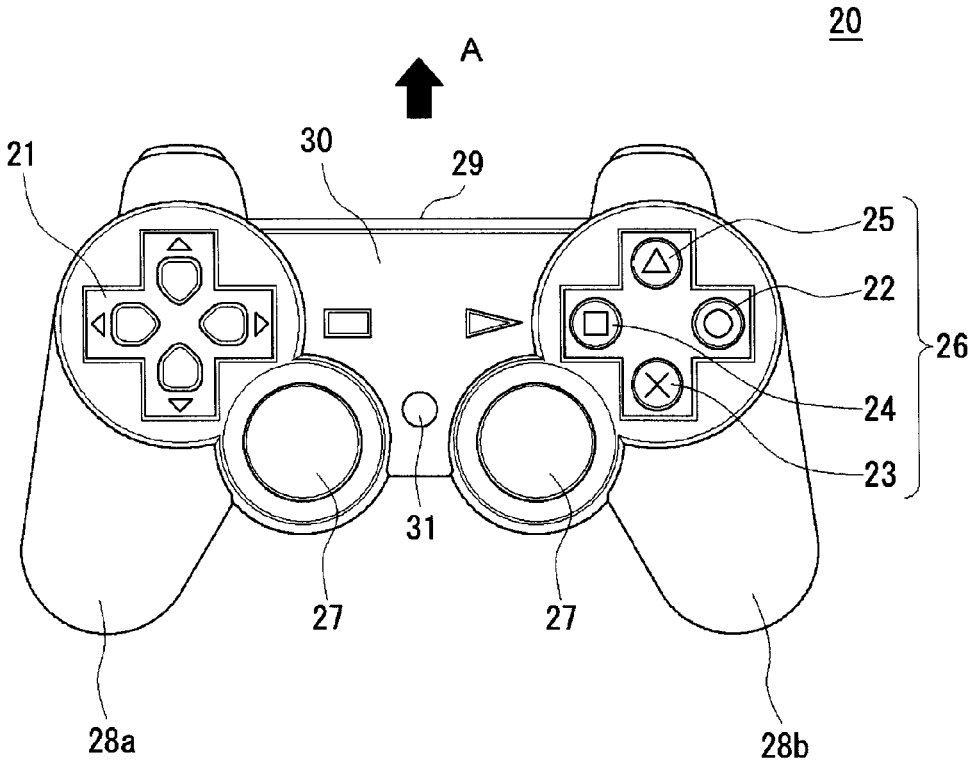

20
A
21
30
29
25
22
26
24
23
31
27
27
28a
28b

FIG.3

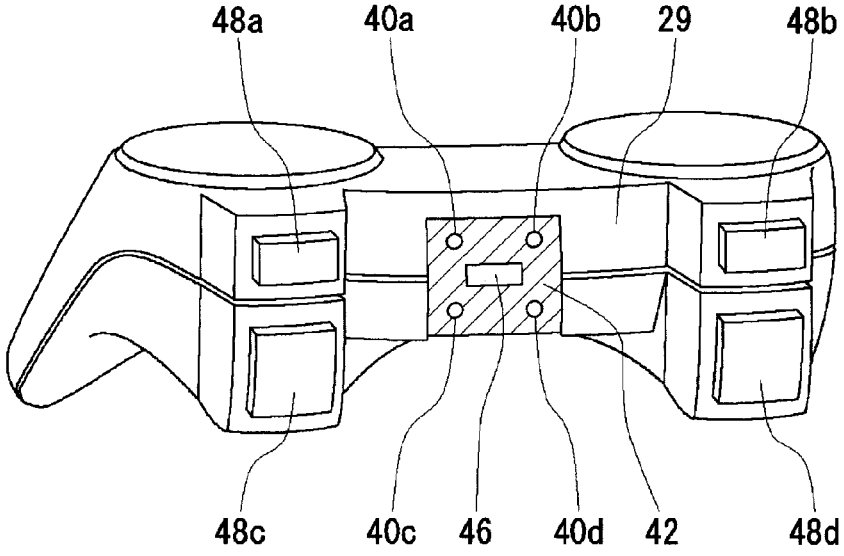
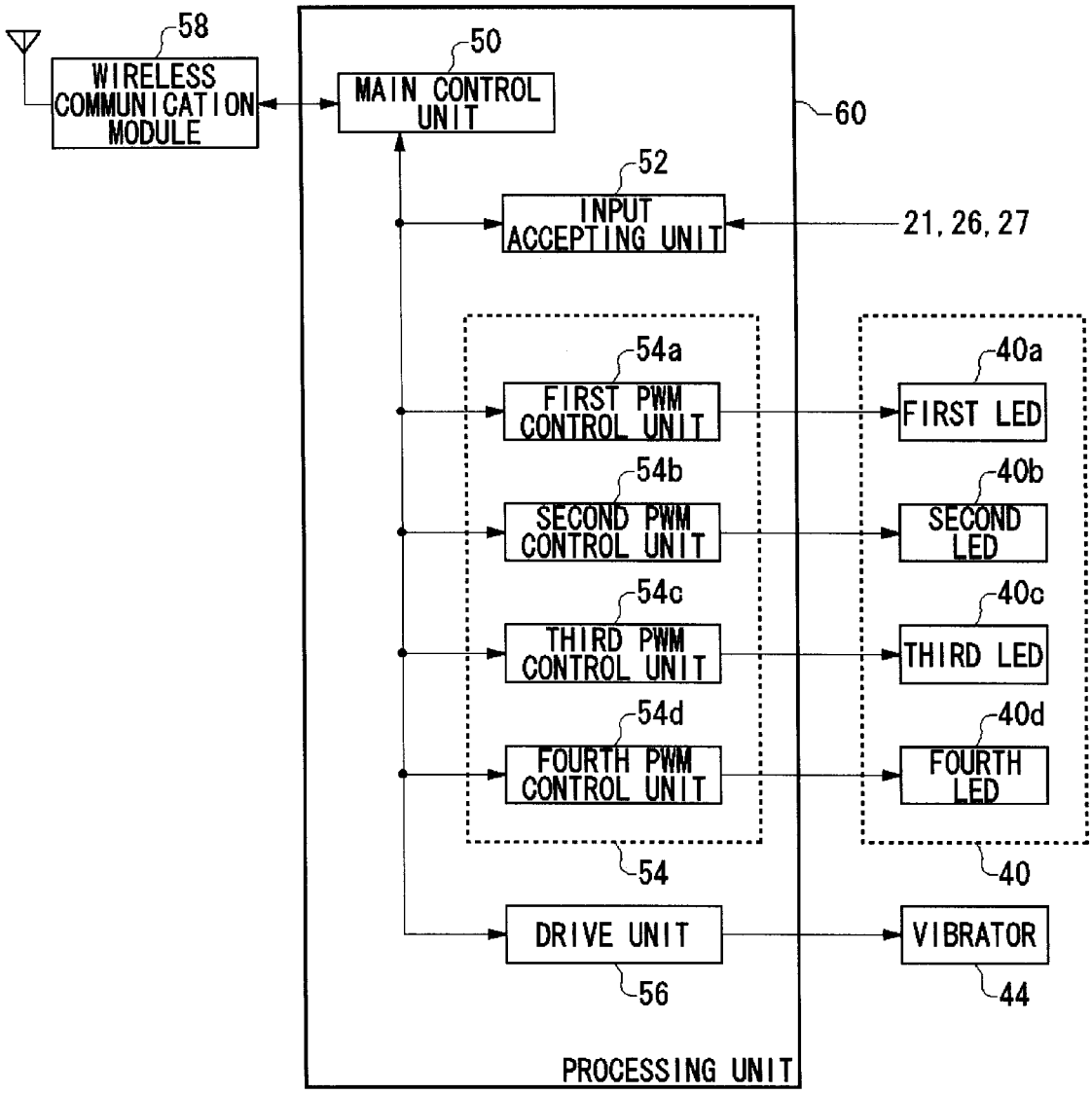

48a
40a
40b
29
48b
48c
40c
46
40d
42
48d
20

FIG.4


58
WIRELESS COMMUNICATION MODULE
50
MAIN CONTROL UNIT
60
52
INPUT ACCEPTING UNIT
21, 26, 27
54a
FIRST PWM CONTROL UNIT
40a
FIRST LED
54b
SECOND PWM CONTROL UNIT
40b
SECOND LED
54c
THIRD PWM CONTROL UNIT
40c
THIRD LED
54d
FOURTH PWM CONTROL UNIT
40d
FOURTH LED
54
40
DRIVE UNIT
56
VIBRATOR
44
PROCESSING UNIT

20

FIG.5

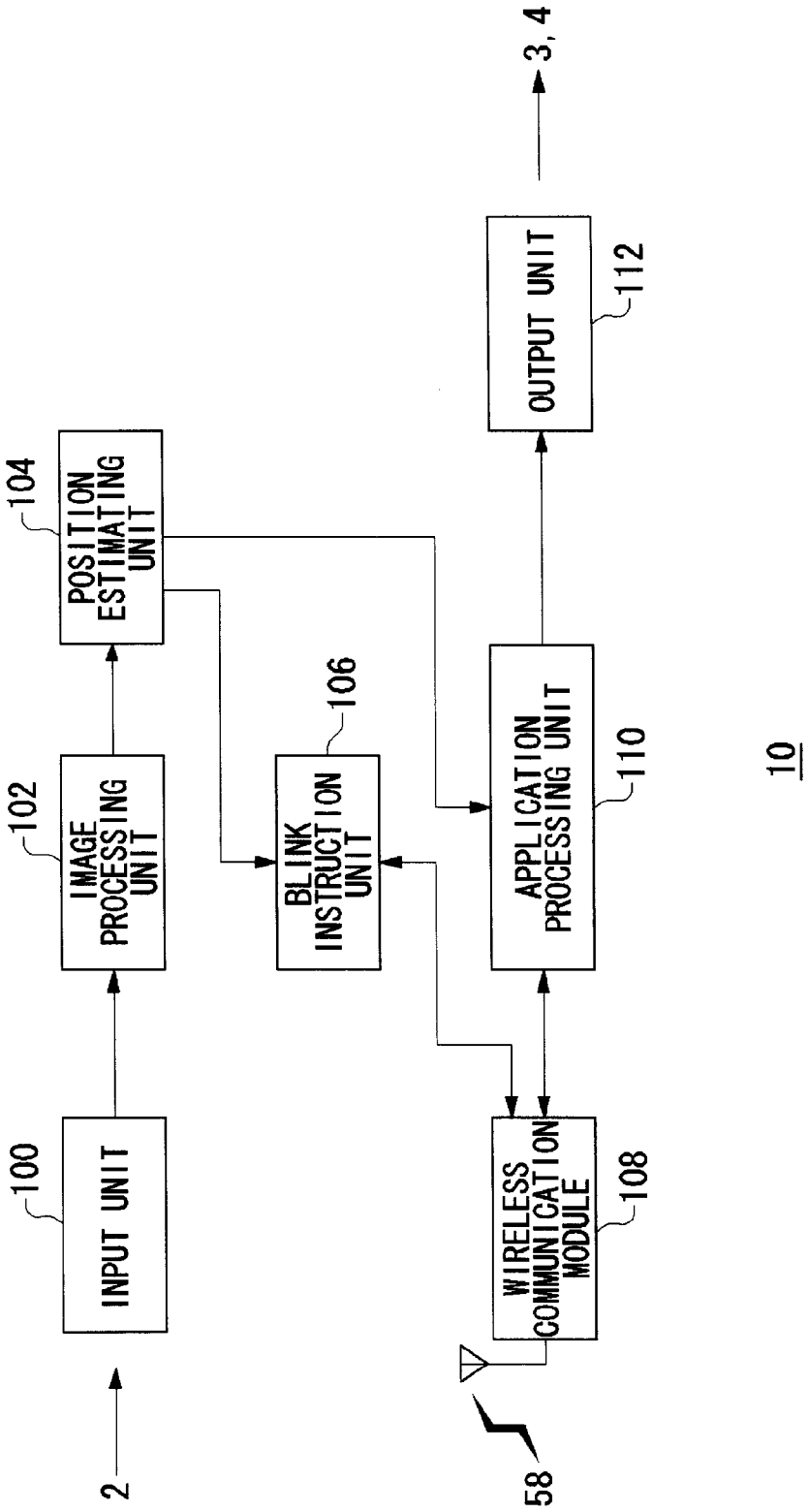

3, 4
OUTPUT UNIT
112
POSITION ESTIMATING UNIT
104
IMAGE PROCESSING UNIT
102
BLINK INSTRUCTION UNIT
106
APPLICATION PROCESSING UNIT
110
10
INPUT UNIT
100
WIRELESS COMMUNICATION MODULE
108
2
58

FIG.6

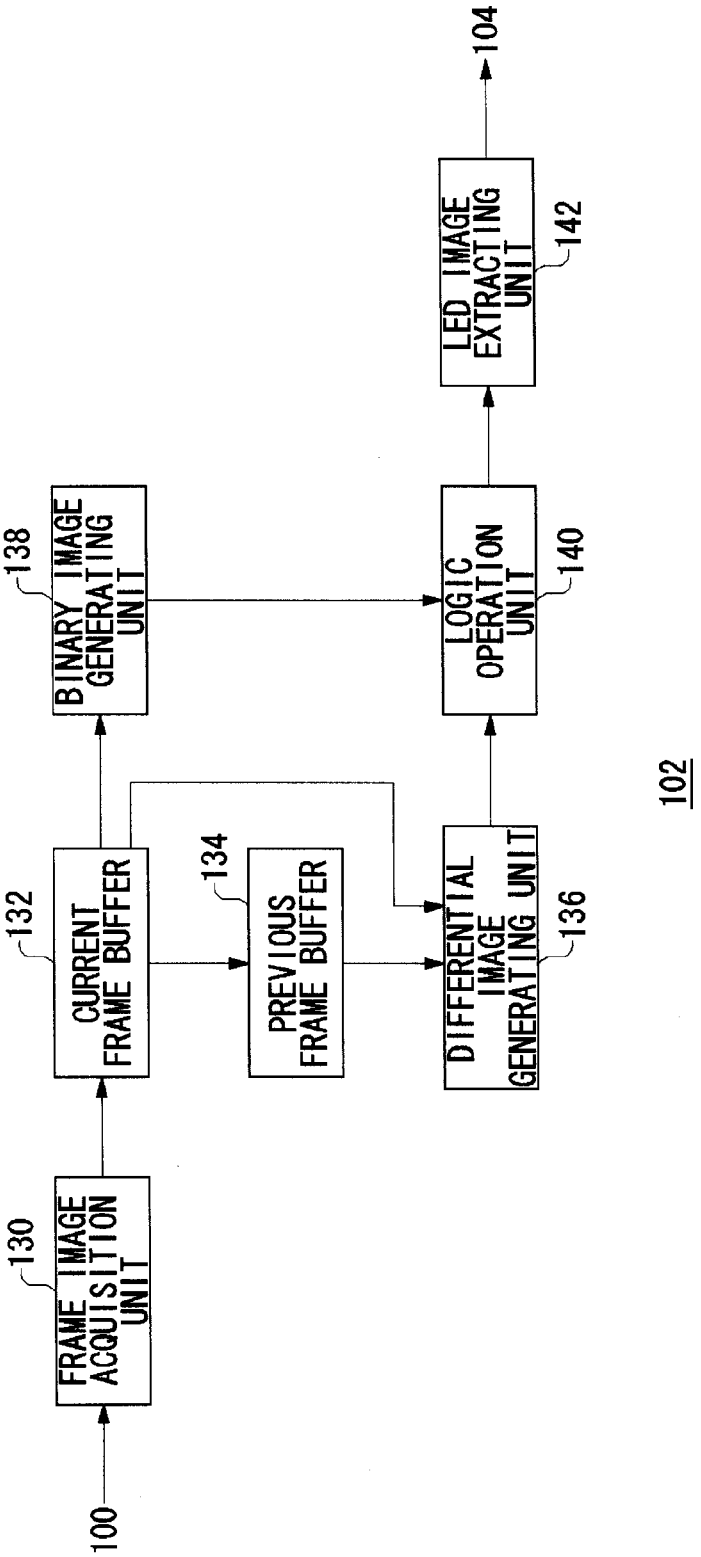

100
FRAME IMAGE ACQUISITION UNIT
130
CURRENT FRAME BUFFER
132
PREVIOUS FRAME BUFFER
134
DIFFERENTIAL IMAGE GENERATING UNIT
136
BINARY IMAGE GENERATING UNIT
138
LOGIC OPERATION UNIT
140
LED IMAGE EXTRACTING UNIT
142
104
102

FIG.7A

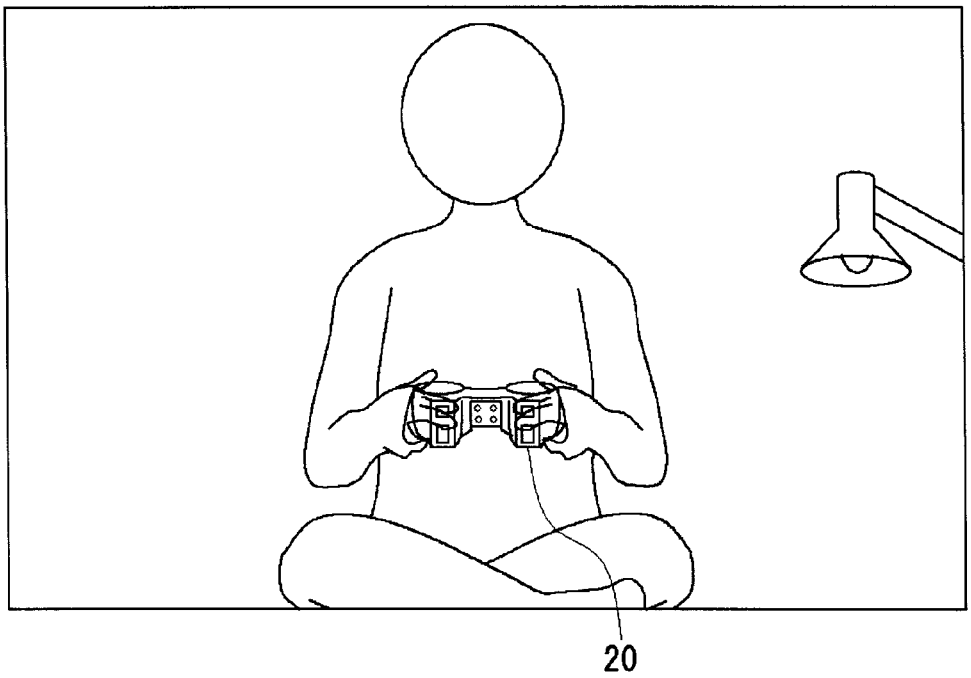


FIG.7B

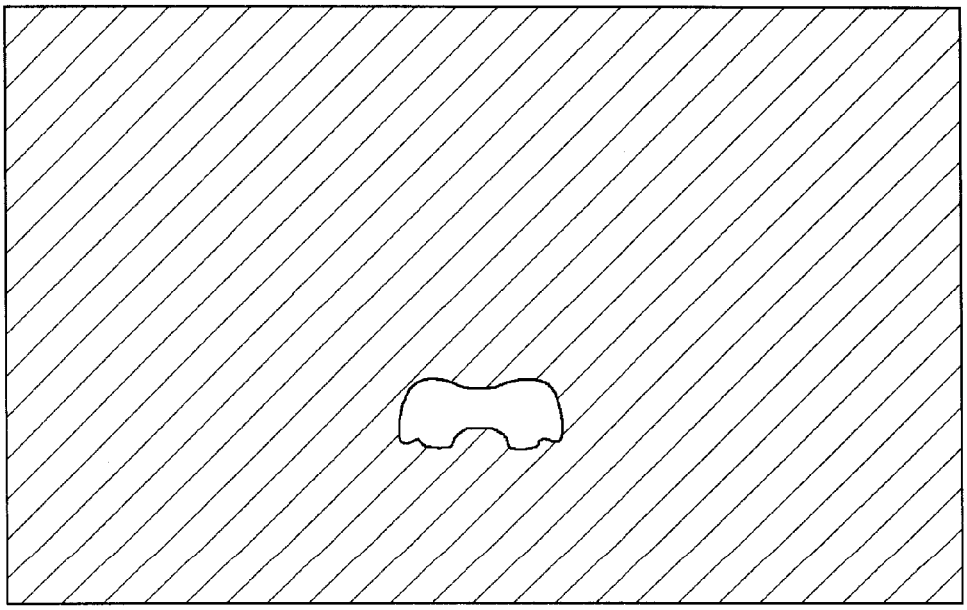


FIG.8A

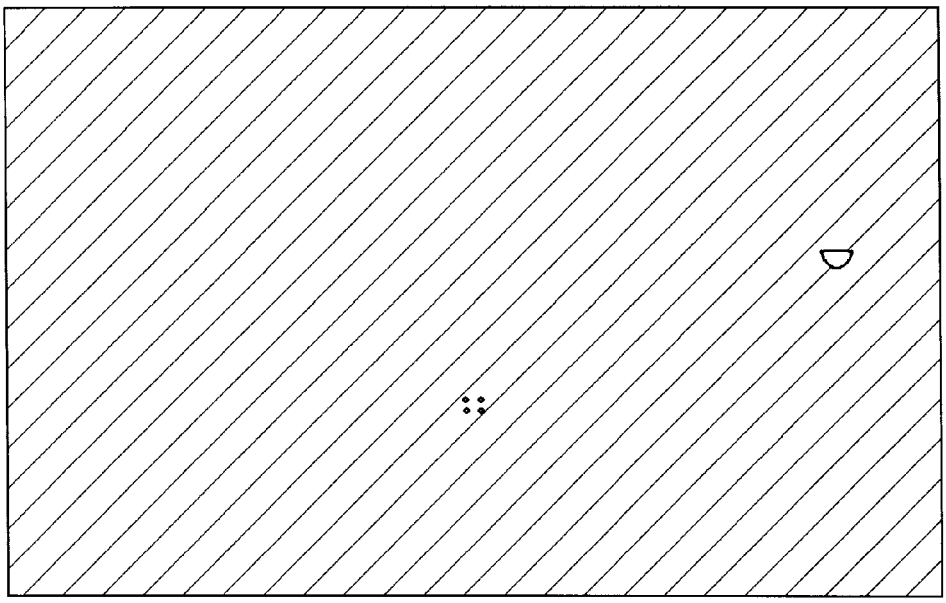


FIG.8B

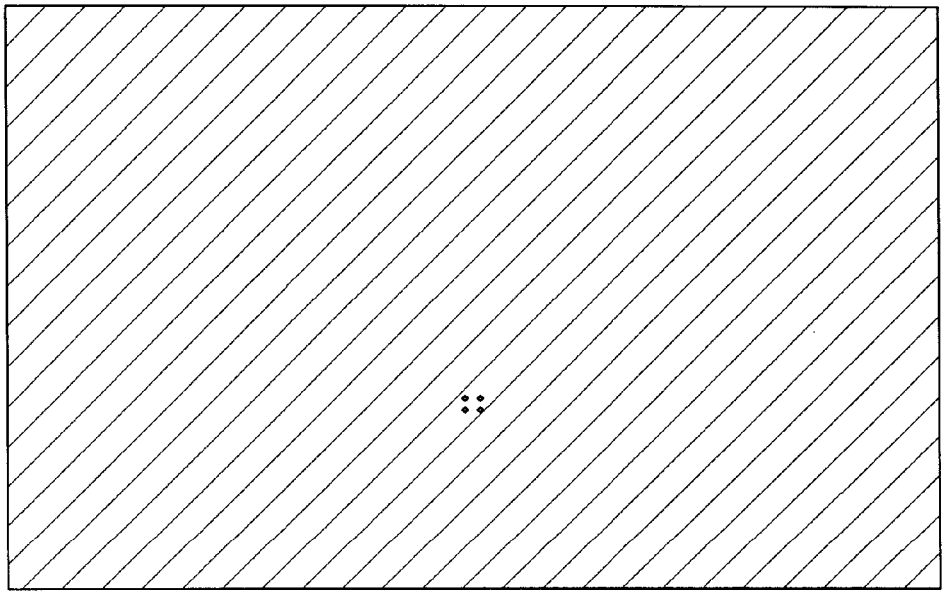


FIG.9

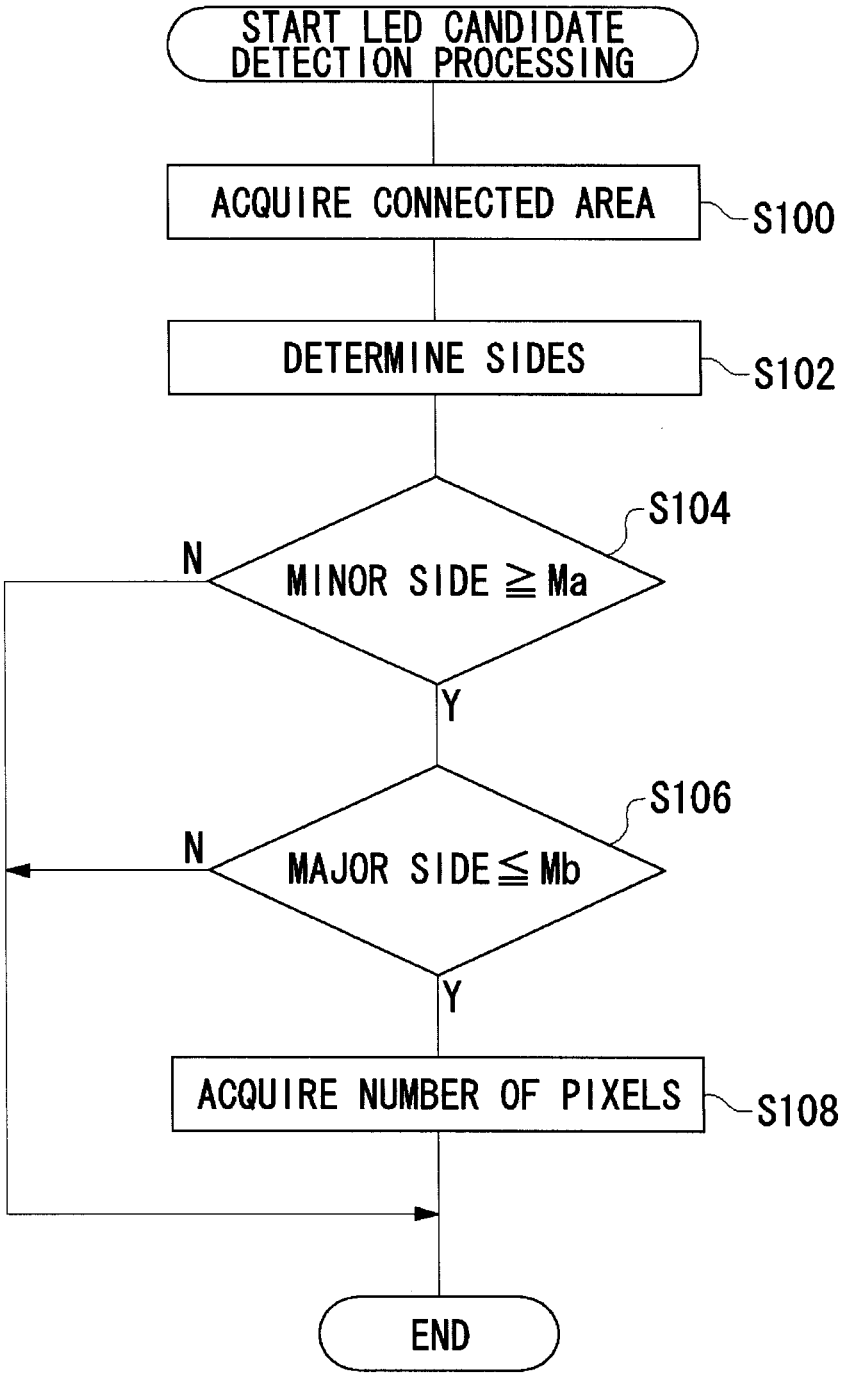

START LED CANDIDATE DETECTION PROCESSING
ACQUIRE CONNECTED AREA
S100
DETERMINE SIDES
S102
S104
MINOR SIDE ≧ Ma
N
Y
S106
MAJOR SIDE ≦ Mb
N
Y
ACQUIRE NUMBER OF PIXELS
S108
END

FIG.10

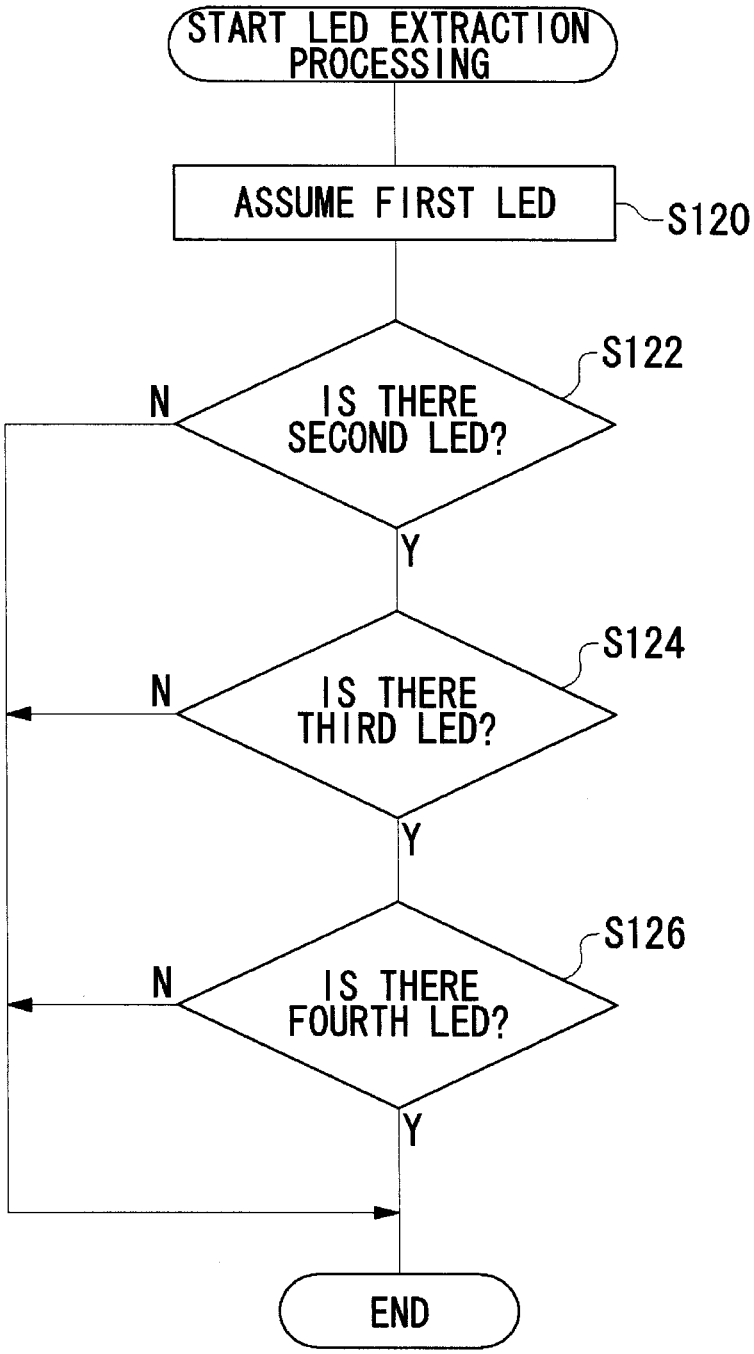

START LED EXTRACTION PROCESSING
ASSUME FIRST LED
S120
S122
IS THERE SECOND LED?
N
Y
S124
IS THERE THIRD LED?
N
Y
S126
IS THERE FOURTH LED?
N
Y
END

FIG.11

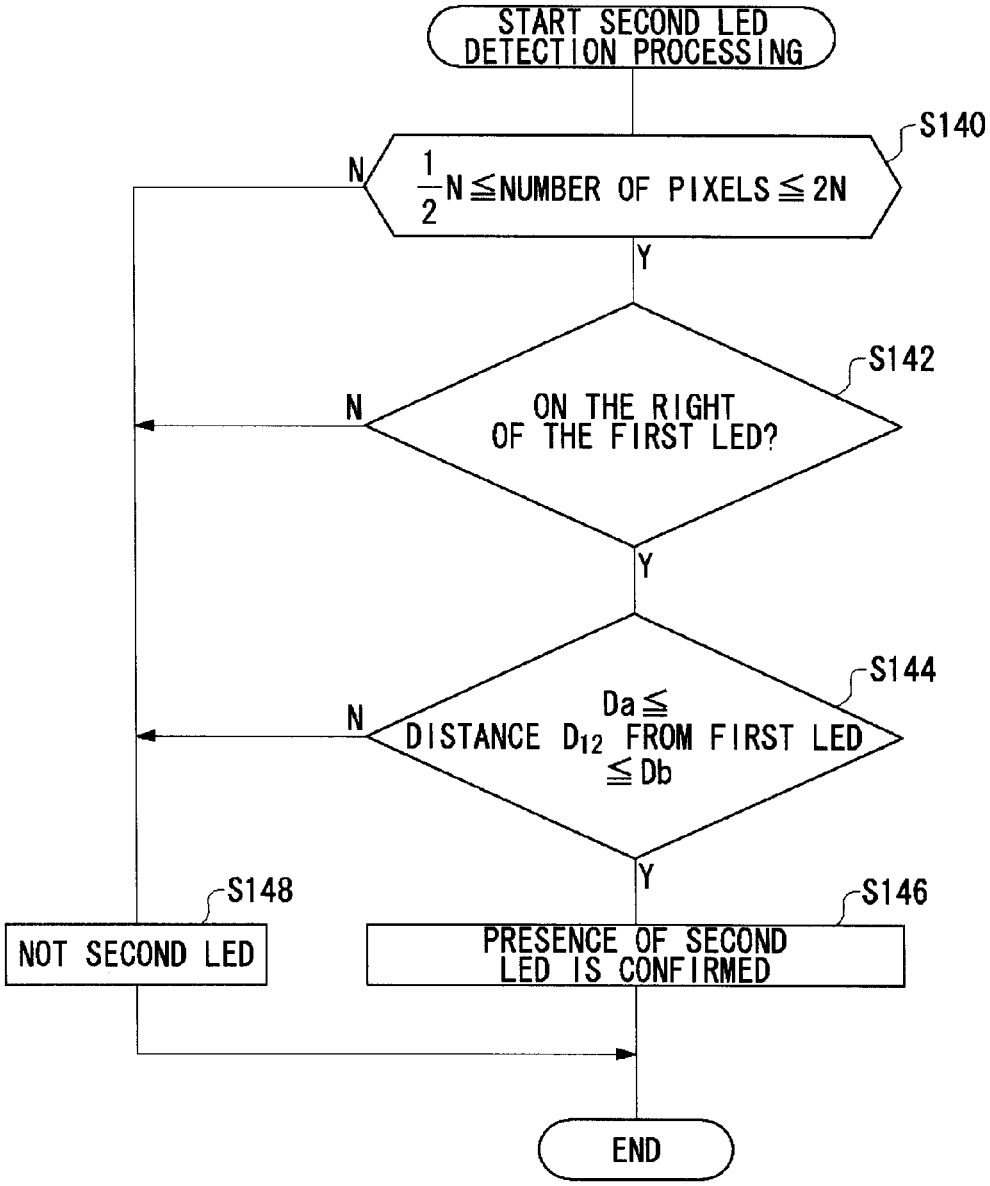

START SECOND LED DETECTION PROCESSING
S140
N
$\frac{1}{2}N \leqq$ NUMBER OF PIXELS $\leqq 2N$
Y
S142
N
ON THE RIGHT OF THE FIRST LED?
Y
S144
N
Da $\leqq$ DISTANCE D_{12} FROM FIRST LED $\leqq$ Db
Y
S148
NOT SECOND LED
S146
PRESENCE OF SECOND LED IS CONFIRMED
END

FIG.12

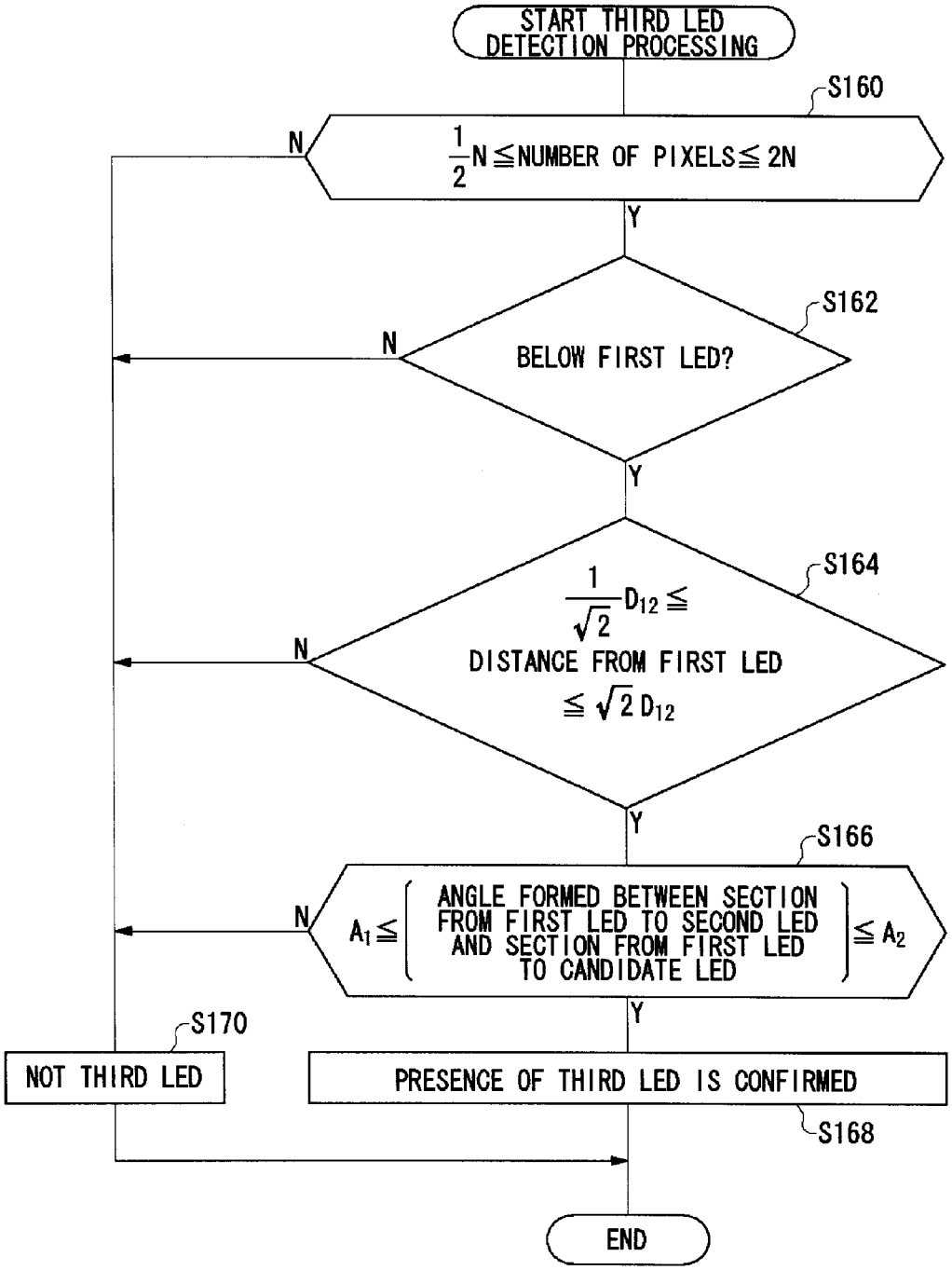

START THIRD LED DETECTION PROCESSING
S160
$\frac{1}{2}N \leqq$ NUMBER OF PIXELS $\leqq 2N$
N
Y
S162
BELOW FIRST LED?
N
Y
S164
$\frac{1}{\sqrt{2}}D_{12} \leqq$ DISTANCE FROM FIRST LED $\leqq \sqrt{2}\,D_{12}$
N
Y
S166
$A_1 \leqq$ ANGLE FORMED BETWEEN SECTION FROM FIRST LED TO SECOND LED AND SECTION FROM FIRST LED TO CANDIDATE LED $\leqq A_2$
N
Y
S170
NOT THIRD LED
PRESENCE OF THIRD LED IS CONFIRMED
S168
END

FIG.13

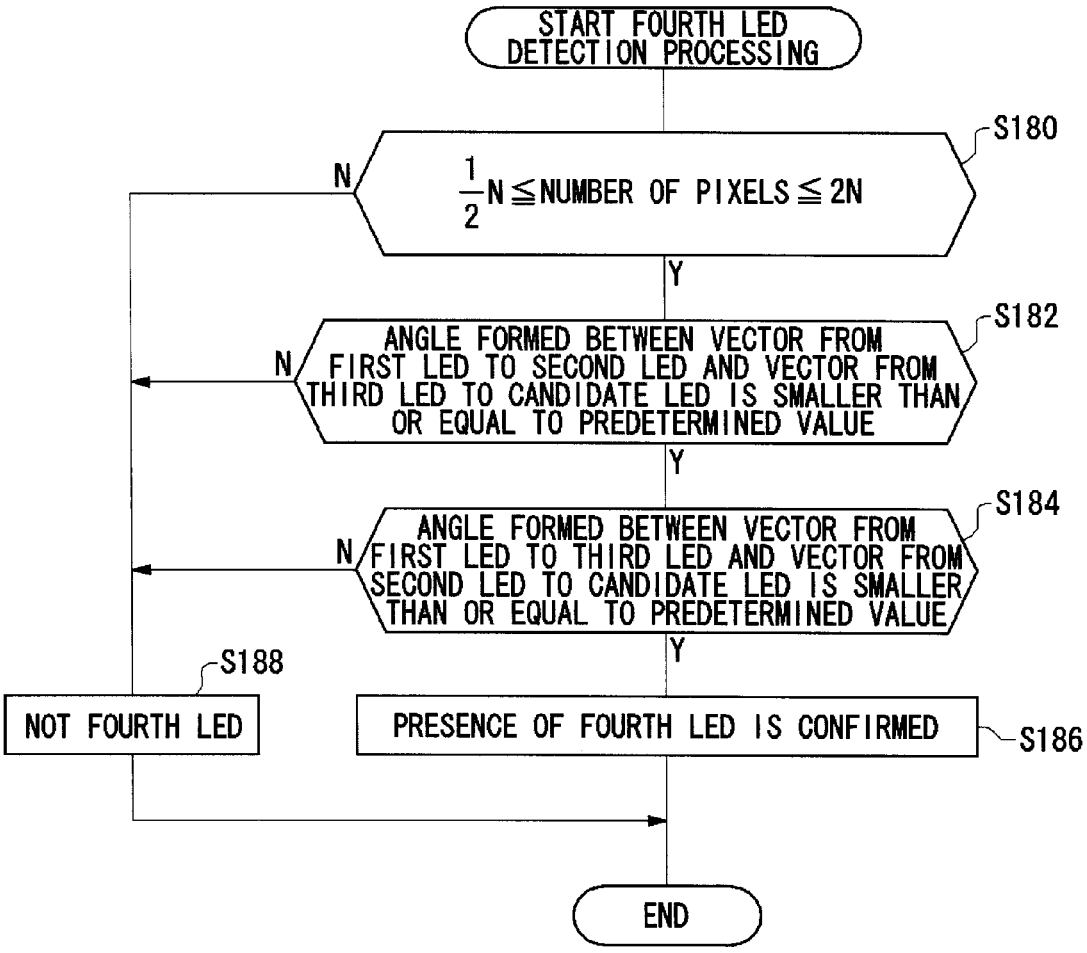

START FOURTH LED DETECTION PROCESSING
S180
N
1/2 N ≦ NUMBER OF PIXELS ≦ 2N
Y
S182
N
ANGLE FORMED BETWEEN VECTOR FROM FIRST LED TO SECOND LED AND VECTOR FROM THIRD LED TO CANDIDATE LED IS SMALLER THAN OR EQUAL TO PREDETERMINED VALUE
Y
S184
N
ANGLE FORMED BETWEEN VECTOR FROM FIRST LED TO THIRD LED AND VECTOR FROM SECOND LED TO CANDIDATE LED IS SMALLER THAN OR EQUAL TO PREDETERMINED VALUE
Y
S188
NOT FOURTH LED
PRESENCE OF FOURTH LED IS CONFIRMED
S186
END

FIG.14A

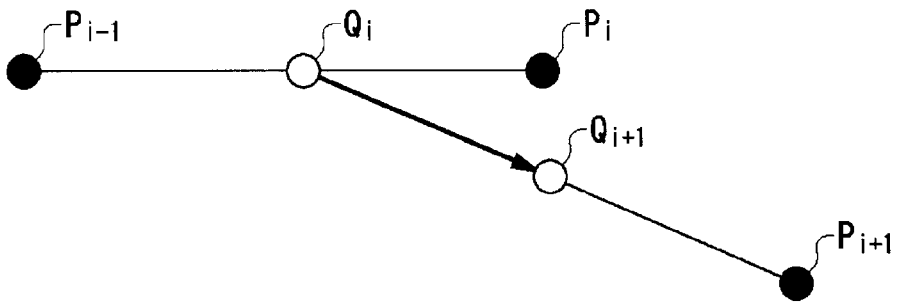
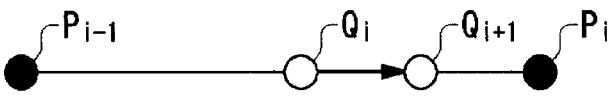


FIG.14B



GAME CONTROLLER WITH PULSE WIDTH MODULATION POSITION DETECTION

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to U.S. patent application Ser. No. 11/683,543, filed Mar. 8, 2007, allowed, and claims priority to Japanese Application No. JP2006-070059, filed Mar. 14, 2006, the entire disclosures of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a game controller.

2. Description of the Related Art

Recently, a technology for capturing a two-dimensional code with a camera, recognizing the code data, and performing predetermined processing associated with that code data has been proposed. Compared to a one-dimensional bar code, a two-dimensional code can store greater amounts of information. Various types of two-dimensional code are put to practical use at present. Accordingly, techniques have been heretofore proposed as to the image recognition of two-dimensional code (for example, see Japanese Patent Laid-Open Publication No. 2000-82108).

There are various types of measuring systems that utilize magnetic, ultrasonic, or optical means in order to acquire three-dimensional positions, orientations, and the like of objects in real space. Magnetic-based measuring systems are susceptible to the influence of electronic equipment in the environment, terrestrial magnetism, and the like. Ultrasonic-based measuring systems are susceptible to ambient pressures, temperatures, and so on. Optical-based measuring systems, on the other hand, are not susceptible to surrounding magnetic fields, air pressures, temperatures, and the like since they use images captured by a camera. The technologies in which a plurality of LEDs arranged on an object are blinked in respective uniquely-defined blink patterns have been proposed. Here, images captured by a two-dimensional image sensor are used to recognize a three-dimensional position and orientation of the object (for example, see Japanese Patent Laid-Open Publication No. 2003-254716). In Japanese Patent Laid-Open Publication No. 2003-254716, LEDs functioning as markers are provided with respective pieces of identification information for unique identification.

With technological advances in recent years, game systems have improved exponentially in terms of their hardware capabilities. This has led to diversified game applications. Lately, game systems comprising a camera and a game apparatus connected to each other have been realized, so that when a user moves his/her body in front of the camera, the game apparatus optically recognizes the user's motion and utilizes it as a game input. In such a gaming environment, the inventor has arrived at a concept for a novel game system and controller which make effective use of a camera in connection with a game apparatus. Moreover, if it is possible to capture the image of an object in real space with the camera, process information regarding the object based on the captured image, and display the processed information on an image display apparatus, then it is expected that useful applications can be produced not only for game systems but also in other environments such as in education and businesses.

SUMMARY OF THE INVENTION

In view of the foregoing, it is a general purpose of an embodiment of the present invention to provide an entertainment system which has a novel application processing function, and an operation input apparatus which is used in the entertainment system.

To solve the foregoing problem, an embodiment of the present invention provides a game controller which has a function of transmitting user's operation inputs to a game apparatus. The game controller includes: a grip to be held by a user; a plurality of input units which are provided on a top of a case so that the user can make operation inputs thereon while holding the grip; a transmission unit which transmits the operation to the game apparatus; and a plurality of light-emitting elements which are provided on a rear of the case.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments will now be described, by way of example only, with reference to the accompanying drawings which are meant to be exemplary, not limiting, and wherein like elements are numbered alike in several Figures, in which:

FIG. **1** is a diagram showing use environment of a game system according to an embodiment of the present invention;

FIG. **2** is a diagram showing the external configuration of a controller;

FIG. **3** is a diagram showing the external configuration of the controller from the rear side;

FIG. **4** is a diagram showing the internal configuration of the controller;

FIG. **5** is a diagram showing the configuration of a game apparatus;

FIG. **6** is a diagram showing the configuration of an image processing unit;

FIG. **7**A is a diagram showing a current frame image, and FIG. **7**B is a diagram showing a differential image between the current frame image and a previous frame image;

FIG. **8**A is a diagram showing a binary image of the current frame image, and FIG. **8**B is a diagram showing an AND image;

FIG. **9** is a flowchart showing the procedure for processing of detecting LED image candidates;

FIG. **10** is a flowchart showing the procedure for LED extraction processing;

FIG. **11** is a flowchart showing the procedure for second LED detection processing shown in **5122** of FIG. **10**;

FIG. **12** is a flowchart showing the procedure for third LED detection processing shown in **5124** of FIG. **10**;

FIG. **13** is a flowchart showing the procedure for fourth LED detection processing shown in **5126** of FIG. **10**; and

FIGS. **14**A and **14**B are diagrams for explaining an algorithm by which a virtual object corresponding to the controller makes a smooth follow-up operation within a game screen.

DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described by reference to the preferred embodiments. This does not intend to limit the scope of the present invention, but to exemplify the invention.

FIG. **1** shows the use environment of a game system according to an embodiment of the present invention. The game system **1** includes an image pickup apparatus **2**, an image display apparatus **3**, a sound output apparatus **4**, a game apparatus **10**, and a controller **20**. The image pickup apparatus **2**, the image display apparatus **3**, the sound output apparatus **4**, and the controller **20** are connected with the game apparatus **10**.

The controller **20** is an operation input apparatus from which a user makes operation inputs. The game apparatus **10** is a processing apparatus which processes a game application

based on operation inputs from the controller **20**, and generates image signals for showing the results of the processing of the game application. It should be appreciated that the technology shown in the present embodiment can also be applied to an entertainment system that has a processing unit for executing other types of applications, not necessarily game applications. As a typical example of the entertainment system, a description will hereinafter be given of the game system **1** which executes a game application.

The image pickup apparatus **2** is a video camera having a CCD imaging sensor, a CMOS image sensor, or the like. It captures images of real space in a cycle, and generates a frame image in each cycle. As an example, the capturing cycle of the image pickup apparatus **2** may be 30 images per second, which coincides with the frame rate of the image display apparatus **3**. The image pickup apparatus **2** is connected with the game apparatus **10** through a USB (Universal Serial Bus) or other such interface.

The image display apparatus **3** is a display for outputting image signals. It receives image signals generated by the game apparatus **10**, and displays a game screen. The sound output apparatus **4** is composed of speakers for outputting sounds. It receives sound signals generated by the game apparatus **10**, and outputs game sounds. The image display apparatus **3** and the sound output apparatus **4** constitute an output apparatus of the game system **1**.

The game apparatus **10** and the image display apparatus **3** may be connected either by cabled means or by wireless means. The game apparatus **10** and the image display apparatus **3** may be connected through AV cables. A home network may be constructed between the game apparatus **10** and the image display apparatus **3** using network (LAN) cables or wireless LAN.

The controller **20** can transmit user's operation inputs to the game apparatus **10**. In the present embodiment, it is configured as a wireless controller which is capable of wireless communication with the game apparatus **10**. The controller **20** and the game apparatus **10** may establish wireless communication therebetween using the Bluetooth™ protocol. The game apparatus **10** can hold wireless communication with a plurality of controllers **20**. In other words, the game system **1** can provide one-to-N connection between the game apparatus **10** and the controllers **20**. The game apparatus **10** functions as a master unit. The controllers **20** function as slave units. It should be appreciated that the controllers **20** are not limited to wireless controllers, but may be cable controllers which are connected to the game apparatus **10** via cables.

The controller **20** is driven by a battery not shown, and is provided with a plurality of buttons and keys for making operation inputs to allow game progress. When a user operates the buttons and keys on the controller **20**, the operation inputs are transmitted to the game apparatus **10** by wireless means. The game apparatus **10** receives the operation inputs pertaining to the game application from the controller **20**, controls the progress of the game according to the operation inputs, and generates game image signals and game sound signals. These game image signals and game sound signals are output through the image display apparatus **3** and the sound output apparatus **4**, respectively. The game apparatus **10** can also transmit a vibration control signal to the controller **20** to cause the controller **20** to vibrate depending on the progress of the game application. The controller **20** contains a vibrator, and makes the vibrator vibrate when it receives the vibration control signal.

In the game system **1** of the present embodiment, the controller **20** is provided with a plurality of light emitting elements. The plurality of light emitting elements are LEDs all of the same color. They have the role of an indicator for indicating a controller number which is set by the game application. The controller number given by the game application is used, for example, when the user selects a game character in starting the game. The controller number must therefore be notified to the user by some means. Accordingly, the controller **20** displays the controller number for the user, for example, with the first LED out of the plurality of LEDS being lit when the controller number is 1, and the second LED being lit when the controller number is 2. It should be appreciated that controller numbers may be expressed by combinations of a plurality of LEDs.

If the controller **20** is a cable controller, the controller number may be determined by the position of the port in the game apparatus **10** where the cable connector extending from the controller **20** is plugged in. Nevertheless, in such cases where the game apparatus **10** is used with an external multiport device having a plurality of ports, it is difficult for users to recognize their controller numbers immediately. Thus, controller numbers are preferably notified to users with the plurality of LEDs.

The game system **1** uses the LEDs of the controller **20** not only as the controller number indicator, but also as a game input means which influences the progress of the game application. In this case, the LED control is switched from the mode of lighting as an indicator to the mode of lighting as an input to the game application. The image pickup apparatus **2** captures an image of the LEDs of the controller **20**, generates a frame image, and supplies it to the game apparatus **10**. The game apparatus **10** acquires the frame image, estimates and acquires the position and orientation of the controller **20** in the frame image based on the positions of LED images, and reflects the acquired position information and/or orientation information in the processing of the game application. That is, the game apparatus **10** of the present embodiment processes the game application using not only the operation inputs made from the controller **20** but also the acquired position information and/or orientation information regarding the controller **20**, thereby generating image signals that shows the results of the processing.

FIG. **2** shows the external configuration of the controller. The controller **20** has arrow keys **21**, analog sticks **27**, and four types of operation buttons **26**. The arrow keys **21**, the analog sticks **27**, and the operation buttons **26** are input units provided on the top **30** of the case. The four types of buttons **22** to **25** are marked with different symbols in different colors in order to distinguish them from each other. More specifically, the ○ button **22** is marked with a red circle, the × button **23** a blue cross, the □ button **24** a purple square, and the Δ button a green triangle. The rear **29** of the case of the controller **20** is provided with a plurality of LEDs.

The user holds a left grip **28***a* with the left hand and a right grip **28***b* with the right hand when operating the controller **20**. The arrow keys **21**, the analog sticks **27**, and the operation buttons **26** are arranged on the case top **30** so that the user can operate them while holding the left grip **28***a* and the right grip **28***b*.

An LED-bearing button **31** is also provided on the case top **30**. The LED-bearing button **31** is used, for example, for instructing the image display apparatus **3** to display a menu screen. The LED-bearing button **31** can also notify the user of incoming mails, and can indicate the battery level of the controller **20** and the like by modifying the lighting status of the LED. For example, the LED is lit in red during charging, lit in green when fully charged, and blinks in red when the level of the battery is low.

The user watches the game screen displayed on the image display apparatus **3** when playing games. The image display apparatus **3** is therefore located beyond the controller **20** as shown by the arrow A. It follows that the LED-bearing case rear **29** usually faces toward the image display apparatus **3**. In the present embodiment, the image pickup apparatus **2** needs to capture an image of the LEDs while the game application is executed. The image pickup apparatus **2** is thus preferably situated so that its image field faces the same direction as the image display apparatus **3**, and so that it faces toward the case rear **29** of the controller **20**. In general, users play games directly in front of the image display apparatus **3**. Accordingly, the image pickup apparatus **2** is arranged so that the direction of its optical axis coincides with the direction faced by the image display apparatus **3**. Specifically, the image pickup apparatus **2** is preferably arranged near the image display apparatus **3** so that its image field covers positions from which the user can view the display screen of the image display apparatus **3**. This allows the image pickup apparatus **2** to capture an image of the user's body and the controller **20**.

FIG. **3** shows the external configuration of the controller from the rear. In FIG. **3**, the arrow keys **21**, the operation buttons **26**, and the like provided on the case top **30** of the controller **20** are omitted. An LED layout area **42** is provided on the case rear **29**. A first LED **40***a*, a second LED **40***b*, a third LED **40***c*, and a fourth LED **40***d* are arranged in the LED layout area **42**. Hereinafter, the first LED **40***a*, the second LED **40***b*, the third LED **40***c*, and the fourth LED **40***d* will be referred to collectively as "LEDs **40**." The LED layout area **42** is provided in the central area of the case rear **29**. A USB connector **46** is provided at the center of the LED layout area **42**. A USB cable extending from the game apparatus **10** may be connected to the USB connector **46** to charge the controller **20**. It should be appreciated that the controller **20** can also be used as a cabled controller when the USB cable is connected.

Operation buttons **48***a*, **48***b*, **48***c*, and **48***d* are provided on the case rear **29** both to the right and to the left of the LED layout area **42**. The operation buttons **48***a*, **48***b*, **48***c*, and **48***d* are located at positions where they can be operated with the tips of the forefingers when the user holds the left grip **28***a* and the right grip **28***b*. This precludes the LEDs **40** from being covered by the forefingers while the operation buttons **48***a*, **48***b*, **48***c*, and **48***d* are operated.

The LEDs **40** are used as indicators for indicating the controller number. From the viewpoint of the user who uses the controller **20**, it is undesirable to arrange the LEDs **40** on the exposed case top **30** since they only have to be checked once. However, when there are other users, the LEDs **40** arranged on the case rear **29** have the advantage of being easily viewable by the other users. Furthermore, since the LED button **31** is positioned on the case top **30**, the LEDs **40** may be confusing if they are arranged there. For these reasons, the controller **20** is configured with the LEDs **40** on the case rear **29**.

The image pickup apparatus **2** acquires RGB luminance values pixel by pixel. In order for lighted LEDs **40** to be detected accurately, it is preferable that the LEDs **40** and the peripheral area around the LEDs **40** have a high lightness contrast. For this purpose, the LED layout area **42** has a darker color than the adjacent color of the case, such as black. The LED layout area **42** is made of a black semitransparent plate, and the LEDs **40** are arranged behind it, i.e., inside the case. Consequently, the LEDs **40** are invisible to the image pickup apparatus **2** when not lit, and an image of them can be captured only when lit. The black semitransparent plate can diffuse light so that the narrow directivity of the LEDs **40** is transformed into wide directivity. Arranging the LEDs **40** in the LED layout area **42** can therefore enhance the contrast of the lighted LEDs **40**. This makes it possible to extract the LED images from frame images effectively in subsequent image processing.

The first LED **40***a*, the second LED **40***b*, the third LED **40***c*, and the fourth LED **40***d* are arranged in a predetermined two-dimensional pattern. For example, the first LED **40***a*, the second LED **40***b*, the third LED **40***c*, and the fourth LED **40***d* are arranged in positions corresponding to the vertexes of a rectangle. The game apparatus **10** is provided with this positional relationship in advance, and uses it when extracting LED images. It should be appreciated that numerals are stamped or printed near the respective LEDs **40**, so that the user can check the numerals near lighted LEDs **40** to recognize the controller number.

FIG. **4** shows the internal configuration of the controller. The controller **20** has a wireless communication module **58**, a processing unit **60**, the LEDs **40**, and a vibrator **44**. The wireless communication module **58** can transmit and receive data to/from a wireless communication module of the game apparatus **10**. The processing unit **60** performs various processing for the controller **20**.

The processing unit **60** includes a main control unit **50**, an input accepting unit **52**, a pulse width modulation (PWM) control unit **54**, and a drive unit **56**. The main control unit **50** exchanges necessary data with the wireless communication module **58**.

The input accepting unit **52** receives input information from the input units, including the arrow keys **21**, the operation buttons **26**, and the analog stick **27**, and sends the information to the main control unit **50**. The main control unit **50** supplies the received input information to the wireless communication module **58**. The wireless communication module **58** transmits it to the game apparatus **10** at the right time. Moreover, when receiving a vibration control signal from the game apparatus **10**, the wireless communication module **58** supplies it to the main control unit **50**. Based on the vibration control signal, the main control unit **50** operates the drive unit **56** which makes the vibrator **44** vibrate. The drive unit **56** may be configured as a switch for driving the vibrator **44**, or as a PWM control unit which adjusts the duty ratio of the supply voltage thereto.

In the present embodiment, the PWM control unit **54** is composed of a first PWM control unit **54***a*, a second PWM control unit **54***b*, a third PWM control unit **54***c*, and a fourth PWM control unit **54***d*. The first PWM control unit **54***a*, the second PWM control unit **54***b*, the third PWM control unit **54***c*, and the fourth PWM control unit **54***d* are provided in order to control the lighting of the first LED **40***a*, the second LED **40***b*, the third LED **40***c*, and the fourth LED **40***d*, respectively. The PWM control unit **54** controls the voltages to be applied to the LEDs **40** by pulse width modulation (PWM). For example, the PWM control unit **54** can PWM-control the applied voltages at high frequencies of several kilohertz, thereby adjusting the luminances of the LEDs **40**. The PWM control unit **54** can also PWM-control the applied voltages at low frequencies of several hertz to one hundred hertz or so, thereby allowing the image pickup apparatus **2** to recognize whether the LEDs **40** are lit or unlit.

In the game system **1** of the present embodiment, a user who wishes to join the game system **1** initially makes his/her controller **20** establish communication with the game apparatus **10**. At this time, identification information regarding the controller **20**, such as a Bluetooth address, is passed to the game apparatus **10**. Subsequent communication will be held based on this Bluetooth address. It should be appreciated that device addresses such as a MAC address may be used if

Bluetooth is not used as the communication protocol. After the communication is established, the user can join the game application.

Here, information for specifying a controller number is transmitted from the game apparatus **10** to the controller **20**. Based on this number specification information, the main control unit **50** lights only an LED or LEDs **40** that correspond(s) to the given controller number. The user can thus recognize the controller number of his/her own controller **20**. It should be appreciated that a control signal for instructing to light LEDs **40** corresponding to the controller number may be transmitted from the game apparatus **10**, instead of the number specification information. As above, the main control unit **50** can light any of the LEDs **40**.

In the game system **1** of the present embodiment, the game apparatus **10** estimates the position and orientation of the controller **20** based on a frame image that is captured when all the LEDs **40***a* to **40***d* are lit. The estimated position and orientation are used as an input to the game application to be run. The game apparatus also accepts operation inputs from the arrow keys **21**, the operation buttons **26**, and the like of the controller **20**. Based on such input information, the game apparatus **10** generates game parameters of the game application, controls the progress of the game, and generates AV data for game images and game sounds. The AV data is output from the image display apparatus **3** and the sound output apparatus **4**. Watching the game screen, the user moves the controller **20** in real space, and also makes operation inputs on the arrow key **21** and the operation button **26** to play the game. A description will now be given of the processing in the game apparatus **10**.

FIG. **5** shows the configuration of the game apparatus. The game apparatus **10** includes an input unit **100**, an image processing unit **102**, a position estimating unit **104**, a blink instruction unit **106**, a wireless communication module **108**, an application processing unit **110**, and an output unit **112**. The processing functions of the game apparatus **10** in the present embodiment are realized by such components as a CPU, a memory, and a program loaded into the memory. The diagram shows functional blocks that can be realized through the cooperation of these components. The program may be built into the game apparatus **10**, or may be supplied from an external recording medium. It will thus be understood by those skilled in the art that these functional blocks may be configured in various forms, including hardware alone, software alone, and combinations of these. In the shown example, the CPU of the game apparatus **10** has the functions of the image processing unit **102**, the position estimating unit **104**, the blink instruction unit **106**, and the application processing unit **110**. Depending on the hardware configuration, the game apparatus **10** may have a plurality of CPUs. In such cases, one of the CPUs may function as the application processing unit **110** which executes the game application. The other CPU(s) may serve as the image processing unit **102** which processes images captured by the image pickup apparatus **2**, the position estimating unit **104**, and the blink instruction unit **106**.

The wireless communication module **108** establishes wireless communication with the wireless communication module **58** of the controller **20**. In the phase of establishing synchronization, the wireless communication module **108** inquires for connection, i.e., performs "inquiry" processing regarding terminal devices including adjacent controllers **20**. Specifically, the wireless communication module **108** broadcasts an IQ (inquiry) packet to terminal devices nearby. The wireless communication modules **58** of controllers **20** that receive the IQ packet return an FHS (Frequency Hop Synchronization) packet, which includes a Bluetooth address and Bluetooth clock information, to the game apparatus **10**. At this time, a fixed hopping pattern dedicated to and defined for inquiry is used for transmission and reception because no consensus as to a frequency hopping pattern has yet been made between the game apparatus **10** and the controllers **20**.

The wireless communication module **108** receives the FHS packets from the controllers **20**, and recognizes the kinds of controllers **20** which are there. Then, it transmits an ID packet to a given controller **20**. This corresponds to "call processing" by the wireless communication module **108**. When a response to the ID packet is returned from the given controller **20**, the wireless communication module **108** transmits an FHS packet to the controller **20**, thereby notifying the controller **20** of its own address and clock. This makes it possible for the game apparatus **10** and the controller **20** to use the same hopping pattern.

When a "call" is made, the controller **20** and the game apparatus **10** form a piconet therebetween and enter a "connected" state. A piconet refers to a network that is formed temporarily between Bluetooth terminals when the terminals are put close to each other. Up to eight Bluetooth terminals can join a single piconet. The connecting controller **20** is given a slave identifier, or a 3-bit address (**1** to **7**) designated for a connected controller **20**, from the wireless communication module **108**. This slave identifier will be called AM_ADDR (Active Member ADDRess). In the "connected" state, control packets for setting a communication link are exchanged to enable "data transfer."

When the controller **20** enters the connected state and joins the game application, the application processing unit **110** assigns a controller number to the controller **20**, and generates number specification information for specifying the controller number. The wireless communication module **108** transmits the number specification information to the controller **20**. Receiving the number specification information, the controller **20** lights the corresponding LED(s) **40**. It should be appreciated that the wireless communication module **108** may transmit a control signal that instructs LEDs **40** to be lit corresponding to the controller number, instead of the number instruction information.

When the game application is started, the blink instruction unit **106** generates a control signal for specifying a blink pattern so that the controller **20** blinks in predetermined cycles. This blink control signal is transmitted from the wireless communication module **108** to the controller **20**.

The input unit **100** is configured as a USB interface, and acquires frame images from the image pickup apparatus **2** at a capturing cycle (for example, 30 frames/second). The image processing unit **102** extracts LED images from frame images according to an LED extraction algorithm to be described later. The position estimating unit **106** acquires position information regarding the LED images from the extracted LED images, and estimates the position and orientation of the controller **20**. The position estimating unit **104** may function as a position acquisition unit since it acquires position information regarding the LED images. It should be appreciated that the position of the controller **20** may be defined as the barycentric point between the images of four LEDs.

The position information and/or the orientation information regarding the controller **20**, estimated from the positions and orientations of the four lit LEDs **40**, is used as an input to the game application. For that purpose, the position information and the orientation information regarding the controller **20**, estimated by the position estimating unit **104**, are sent to the application processing unit **110** in succession and reflected in the processing of the application. User inputs made by operating the arrow key **21** and the like of the

controller **20** are also sent to the application processing unit **110** through the wireless communication module **108**. The application processing unit **110** advances the game based on the position and orientation information regarding the controller **20** and the operation inputs from the controller **20**, and generates image signals and sound signals that show the results of the processing of the game application. The image signals and the sound signals are sent from the output unit **112** to the image display apparatus **3** and the sound output apparatus **4** for output, respectively.

FIG. **6** shows the configuration of the image processing unit. The image processing unit **102** includes a frame image acquisition unit **130**, a current frame buffer **132**, a previous frame buffer **134**, a differential image generating unit **136**, a binary image generating unit **138**, a logic operation unit **140**, and an LED image extracting unit **142**.

The frame image acquisition unit **130** acquires frame image data from the input unit **100**, and stores it temporarily in the current frame buffer **132**. The previous frame buffer **134** contains data regarding the last frame image. The differential image generating unit **136** generates a differential image between the current frame data stored in the current frame buffer **132** and the previous frame data stored in the previous frame buffer **134**. A differential image function F(x, y) is given by the following equation

$$F(x,y)=\sqrt{(Pr-Cr)^2+(Pg-Cg)^2+(Pb-Cb)^2}-Th \quad ...(1)$$

where Pr is the R pixel value, Pg is the G pixel value, and Pb is the B pixel value of the previous frame data at coordinates (x, y) in that frame image, and Cr is the R pixel value, Cg is the G pixel value, and Cb is the B pixel value of the current frame data at the same coordinates (x, y).

Here, Th is a predetermined threshold.

If F(x, y) is greater than 0, the pixel values at coordinates (x, y) are encoded to "1". Then, the pixel will be displayed in white. On the other hand, if F(x, y) is less than or equal to 0, the pixel values at coordinates (x, y) are encoded to "0". Then, the pixel will be displayed in black. It follows that the differential image generated by the differential image generating unit **136** is a binarized image. The differential image can be generated to eliminate the effect of objects that remain motionless between the previous frame image and the current frame image.

The binary image generating unit **138** binarizes the current frame data using a predetermined threshold, thereby generating a binary image. The binary image generating unit **138** encodes the pixel values of pixels that have luminances higher than the predetermined threshold into "1." It encodes the pixel values of pixels that have luminances lower than or equal to the predetermined threshold into "0." Generating a binary image of the current frame image can extract only the bright objects in the current frame image.

The logic operation unit **140** performs a logic operation between the differential image generated by the differential image generating unit **136** and the binary image generated by the binary image generating unit **138**, thereby generating a logic operation image. More specifically, the logic operation unit **140** performs an AND operation between the pixel values of the differential image and the pixel values of the binary image pixel by pixel, thereby generating an AND image. This AND image is generated by performing an AND operation between the corresponding pixels of the differential image and the binary image mathematically.

FIG. **7**A shows a current frame image. The current frame image shows a situation where a user holds the controller **20** for game play, and a lamp is lit on the right. Here, the LEDs **40** of the controller **20** are all lit. All the LEDs **40** emit light in an identical lighting pattern with an identical luminance.

FIG. **7**B shows a differential image between the current frame image and a previous frame image. When the controller **20** is moved from its position in the previous frame image, the differential image is generated from the equation (1). In this example, the controller **20** and at least some of the areas of the body that move with the controller **20** are acquired as a white image (with pixel values of "1"). Such a white image is not always acquired, however, and what is shown in FIG. **7**B is just an example of the differential image which might be generated when the equation (1) is satisfied. The lamp is not included in the differential image since it is motionless. It should be appreciated that the white image of the controller **20** will not be acquired if the user does not move the controller **20**.

FIG. **8**A shows a binary image of the current frame image. In the binary image, high-luminance areas of FIG. **7**A, i.e., the lighted LEDs and the illumination lamp are turned into white images. For the sake of reducing foreign noise, the threshold for the binarization processing is desirably set to a luminance value that is determined by subtracting a predetermined margin value from the luminance of the LED emission.

FIG. **8**B shows an AND image. The AND image is obtained by performing an AND operation between the differential image shown in FIG. **7**B and the binary image shown in FIG. **8**A. In the differential image and the binary image, the white pixels have pixel values of "1" and the black pixels have pixel values of "0". Thus, only the pixels that are present as white pixels in both images appear as white pixels in the AND image.

As above, the differential image and the binary image can be logical AND operated to generate an AND image which is easier to extract LED images from. The AND image is sent to the LED image extracting unit **142**.

When the AND image has been generated, the previous frame data retained in the previous frame buffer **134** is overwritten with the current frame data retained in the current frame buffer **132**. This overwrite processing may be performed immediately after the previous frame buffer **134** is read by the differential image generating unit **136**. Subsequently, the current frame data retained in the current frame buffer **132** is overwritten with the next frame data, and the next frame is subjected to the process of generating an AND image.

The LED image extracting unit **142** extracts LED images from the AND image. To extract LED images, the LED image extracting unit **142** initially detects candidates for LED images. Then, the LED image extracting unit **142** assumes any one of the candidates to be the first LED **40***a*, and searches the peripheral area for a candidate for an LED image that may be the second LED **40***b*. If the second LED **40***b* is found, the LED image extracting unit **142** searches the peripheral area of the first LED **40***a* again for a candidate for an LED image that may be the third LED **40***c*. If the third LED **40***c* is found, it searches the peripheral area for a candidate for an LED image that may be the fourth LED **40***d*. Note that the LED image extracting unit **142** has been provided with the two-dimensional pattern to be formed by the plurality of LEDs **40** in advance, and uses this two-dimensional pattern to extract the LED images. For the sake of convenience, the following description will deal with the case where the first LED **40***a*, the second LED **40***b*, the third LED **40***c*, and the LED **40***d* form the vertexes of a square on the case rear **29** of the controller **20**.

It should be appreciated that the LED image extracting unit **142** can also extract LED images from the binary image

without using the AND image. Binary images contain noise as well as LED images. It is possible, however, to detect the positions and orientations of LED images by using binary images if the LED images cannot be obtained from differential images. The procedure shown below can be performed by using either an AND image or a binary image. Since AND images contain less noise components other than the LED images, the use of the AND image improves the processing speed.

FIG. **9** is a flowchart showing the procedure for detecting LED image candidates. The LED image extracting unit **142** acquires an area of the AND image where consecutive white pixels (pixels having pixel values of "1") are found, as a single connected area (S**100**). Next, the LED image extracting unit **142** extracts the edges of the connected area of white pixels, and determines a minor side and a major side (S**102**).

The LED image extracting unit **142** determines whether or not the minor side contains pixels more than or equal to a predetermined number of pixels Ma (S**104**). If the minor side contains pixels less than the number of pixels Ma (N at S**104**), the LED image extracting unit **142** stops processing this connected area of white pixels since it is not an LED image. If the minor side contains pixels more than or equal to the number of pixels Ma (Y at S**104**), the LED image extracting unit **142** determines whether or not the major side contains pixels less than or equal to a predetermined number of pixels Mb (S**106**). If the major side contains pixels more than the number of pixels Mb (N at S**106**), the LED image extracting unit **142** stops processing this connected area of white pixels since it is not an LED image. If the major side contains pixels less than or equal to the number of pixels Mb (Y at S**106**), the LED image extracting unit **142** acquires the number of pixels that constitute the connected area of white pixels since it is a candidate for an LED image (S**108**). This LED image candidate detection processing is repeated on all the connected areas of white pixels. The LED image candidates included in the AND image can be detected in this way. Note that the coordinates of the LED image candidates are determined to be the barycenters of the respective connected areas.

FIG. **10** is a flowchart showing the procedure for LED extraction processing. The LED image extracting unit **142** assumes any one of the detected LED image candidates to be the first LED **40***a* (S**120**). Next, it determines whether or not there is any LED image candidate that satisfies the conditions for it to be the second LED **40***b* with respect to the first LED **40***a* (S**122**). If there is any LED image candidate that may be the second LED **40***b* (Y at S**122**), the LED image extracting unit **142** determines whether or not there is any LED image candidate that satisfies the conditions for it to be the third LED **40***c* with respect to the first LED **40***a* and the second LED **40***b* (S**124**). If there is any LED image candidate that may be the third LED **40***c* (Y at S**122**), the LED image extracting unit **142** determines whether or not there is any LED image candidate that satisfies the conditions for it to be the fourth LED **40***d* with respect to the first LED **40***a*, the second LED **40***b*, and the third LED **40***c* (S**126**). If there is any LED image candidate that may be the fourth LED **40***d* (Y at S**126**), it follows that the first LED **40***a* to the fourth LED **40***d* of the controller **20** have been extracted. It should be appreciated that if there is no candidate for the second LED image (N at S**122**), if there is no candidate for the third LED image (N at S**124**), or if there is no candidate for the fourth LED image (N at S**126**), then another LED image candidate is assumed to be the first LED **40***a* and the process of FIG. **8** is performed again.

For the sake of reducing the processing load, the LED extraction process may be performed on the assumption that the orientation of the controller **20** is not inclined beyond a predetermined angle. Since the LEDs **40** have a relatively high directivity, it is difficult for the image pickup apparatus **2** to receive their light when the controller **20** is inclined greatly. Utilizing this directivity of the LEDs **40**, it is possible to significantly reduce the processing load in searching for LED image candidates by performing the LED image extraction process with the assumption that the inclination from the first LED **40***a* will not exceed a predetermined angle (for example, 45°).

Since the present embodiment uses the differential image between the previous frame image and the current frame image for the above process, the images of the LEDs **40** are excluded from the differential image when the controller **20** is motionless. The use of the differential image therefore does not ensure that LED images will always be found by the LED extraction processing shown in FIG. **10**. If no LED image is found in the LED extraction processing shown in FIG. **10**, the position estimating unit **104** acquires the position information and orientation information regarding the controller **20** in the previous frame, estimating that the controller **20** has remained stationary in the same position as in the previous frame. At this point, the position estimating unit **104** may extract LED images by using the binary image.

FIG. **11** is a flowchart showing the procedure for the second LED detection process shown in **5122** of FIG. **10**. Suppose that the number of pixels constituting the LED image candidate that is assumed to be the first LED **40***a* is N. Initially, the LED image extracting unit **142** determines whether or not an LED image candidate has pixels no less than ½×N and no more than 2N (S**140**). This is based on the fact that LED images will not be much different from that of the first LED **40***a* in size or shape. If the number of pixels constituting the LED image candidate falls within the predetermined range around the number of pixels N (Y at S**140**), the LED image extracting unit **142** determines whether or not the LED image candidate lies on the right of the first LED **40***a* (S**142**). Whether it is considered to be to the right or not is on the basis of whether or not the LED image candidate falls within the range of 45° top right and 45° bottom right of the first LED **40***a*. If it is to the right of the first LED **40***a* (Y at S**142**), the LED image extracting unit **142** determines whether or not the distance D_{12} between the first LED **40***a* and the LED image candidate is no less than Da and no greater than Db (S**144**). This determination is made on the basis that the candidate cannot be the second LED **40***b* if the two are spaced too close or too far from each other. If the distance D_{12} is no less than Da and no greater than Db (Y at S**144**), it is determined that the LED image candidate may be the second LED **40***b*. This confirms the presence of the second LED **40***b* (S**146**). On the other hand, if the number of pixels constituting the LED image candidate does not fall within the predetermined range (N at S**140**), if the candidate is not to the right of the LED **40***a* (N at S**142**), or if the distance D_{12} does not fall within the predetermined range (N at S**144**), then it is determined that the LED image candidate is not the second LED **40***b*.

FIG. **12** is a flowchart showing the procedure for the third LED detection process shown in **5124** of FIG. **10**. Suppose that the number of pixels constituting the LED image candidate that is assumed to be the first LED **40***a* is N. Initially, the LED image extracting unit **142** determines whether or not an LED image candidate has pixels no less than ½×N and no more than 2N (S**160**). If the number of pixels constituting the LED image candidate falls within the predetermined range around the number of pixels N (Y at S**160**), the LED image extracting unit **142** determines whether or not the LED image candidate lies below the first LED **40***a* (S**162**). Whether it is

considered to be below or not is determined on the basis of whether or not the LED image candidate falls within the range of 45° bottom left and 45° bottom right of the first LED **40***a*. If it is below the LED **40***a* (Y at S**162**), the LED image extracting unit **142** determines whether or not the distance between the first LED **40***a* and the LED image candidate is no less than $1/\sqrt{2}\times D_{12}$ and no greater than $\sqrt{2}\times D_{12}$ (S**164**). This determination is made on the basis that the candidate cannot be the third LED **40***c* if the two are spaced too close or too far from each other. If the distance is no less than $1/\sqrt{2}\times D_{12}$ and no greater than $\sqrt{2}\times D_{12}$ (Y at S**164**), the LED image extracting unit **142** determines whether or not the angle formed between the segment from the first LED **40***a* to the second LED **40***b* and the segment from the first LED **40***a* to the LED image candidate falls within a predetermined range (S**166**). At this point, if the angle falls within the predetermined range (Y at S**166**), it is determined that the LED image candidate may be the third LED **40***c*. This confirms the presence of the third LED **40***c* (S**168**). On the other hand, if the number of pixels constituting the LED image candidate does not fall within the predetermined range (N at S**160**), if the candidate is not below the LED **40***a* (N at S**162**), if the distance from the first LED **40***a* does not fall within the predetermined range (N at S**164**), or if the angle does not fall within the predetermined range (N at S**166**), then it is determined that the LED image candidate is not the third LED **40***c* (S**170**).

FIG. **13** is a flowchart showing the procedure for the fourth LED detection process shown in **5126** of FIG. **10**. Suppose that the number of pixels constituting the LED image candidate that is assumed to be the first LED **40***a* is N. Initially, the LED image extracting unit **142** determines whether or not an LED image candidate has pixels no less than ½×N and no more than 2N (S**180**). If the number of pixels constituting the LED image candidate falls within the predetermined range around the number of pixels N (Y at S**180**), the LED image extracting unit **142** determines whether or not the angle formed between a vector extending from the first LED **40***a* to the second LED **40***b* and a vector extending from the third LED **40***c* to the LED image candidate is no greater than a predetermined value (S**182**). If the angle formed between the vector extending from the first LED **40***a* to the second LED **40***b* and the vector extending from the third LED **40***c* to the LED image candidate is smaller than or equal to the predetermined value (Y at S**182**), then the LED image extracting unit **142** determines whether or not the angle formed between a vector extending from the first LED **40***a* to the third LED **40***c* and a vector extending from the second LED **40***b* to the LED image candidate is no smaller than a predetermined value (S**184**). If the angle formed between the vector extending from the first LED **40***a* to the third LED **40***c* and the vector extending from the second LED **40***b* to the LED image candidate is smaller than or equal to the predetermined value (Y at S**184**), it is determined that the LED image candidate may be the fourth LED **40***d*. This confirms the presence of the fourth LED **40***d* (S**186**). On the other hand, if the number of pixels constituting the LED image candidate does not fall within the predetermined range (N at S**180**), if the angle formed between the vector extending from the first LED **40***a* to the second LED **40***b* and the vector extending from the third LED **40***c* to the LED image candidate exceeds the predetermined value (N at S**182**), or if the angle formed between the vector extending from the first LED **40***a* to the third LED **40***c* and the vector extending from the second LED **40***b* to the LED image candidate exceeds the predetermined value (N at S**184**), then the LED image candidate is determined not to be the fourth LED **40***d* (S**188**).

Through the foregoing process, the LED image extracting unit **142** can extract the images of the first LED **40***a* to the fourth LED **40***d* from the AND image. Position information regarding the extracted images of the first LED **40***a* to the fourth LED **40***d* is sent to the position estimating unit **104**.

The position estimating unit **104** acquires position information regarding the images of the first LED **40***a* to the fourth LED **40***d* in the frame image based on the two-dimensional arrangement of the LEDs **40** on the controller **20**. The position estimating unit **104** determines an affine transformation between the first LED **40***a*, the second LED **40***b*, the third LED **40***c*, and the fourth LED **40***d*, and thereby calculates the position and orientation of the controller **20** in real space. The position of the controller **20** in real space is expressed by coordinates (X, Y, Z) on an orthogonal coordinate system. The orientation in real space is expressed by the angles of rotation around the X-axis, the Y-axis, and the Z-axis. Determining the coordinates and the angles of rotation as to the three axes, the position estimating unit **104** can estimate the position within the space, including the distance from the image pickup apparatus **2**. The position estimating unit **104** may also determine an affine transformation to estimate the position of the controller **20** within a frame image. For example, the XY coordinates in XYZ space can be used to obtain the position within the frame image. The position estimating unit **104** sends the estimated position and orientation of the controller **20** to the application processing unit **110**.

To avoid misidentification of the LEDs **40**, the position estimating unit **104** processes the currently acquired positions of the LED images as an error if the amount of change between the previously acquired positions of the LED images and the currently acquired positions of the LED images exceeds a predetermined value. That is, when the positions or orientations vary more than a predetermined value during a single frame, it might be the case that other objects are possibly misidentified as the LEDs **40** due to foreign factors. The extracted position information regarding the LEDs **40** is discarded for this reason.

Even in those cases, however, the controller **20** might actually be moved by that large amount of change. Therefore, the position estimating unit **104** may count the number of errors occurring in succession, and process the acquired positions of the LED images as normal ones when the count reaches a predetermined value.

The position estimating unit **104** can also estimate the directions of movement and the speeds of movement of the LEDs **40**, for example, based on the current frame image or the AND image. For example, when the shutter speed of the image pickup apparatus **2** is reduced, the LEDs **40** may be captured as elliptic or rectangular images. Accordingly, the directions of movement as well as the moving speeds can be estimated from the shapes of the LED images. For example, if the directions and the speeds of movement can be estimated, it is possible to estimate the position and orientation of the controller **20** even if the controller **20** abruptly disappears from the view of the image pickup apparatus **2**. When the shapes of all the LEDs **40** are leaning in the same direction, the direction and the speed of movement of the controller **20** may be estimated.

The application processing unit **110** reflects the estimated position and orientation of the controller **20** as a game input in the processing of the game application. This reflection may be effected in various ways. In a most intuitive fashion, a virtual object following the estimated position of the controller **20** may be displayed at the corresponding position in the game image. When the user moves the controller **20** with respect to

the image pickup apparatus **2**, the virtual object can be moved to follow the motion in the game image.

It should be appreciated that the positions and orientations of the LEDs **40** are ideally determined in each frame image and accordingly reflected on the game images in succession. Nevertheless, it may sometimes be impossible to determine the positions and orientations of the LEDs **40** in frame images, depending on environmental conditions including the orientation of the controller **20** and the ambient light. When such a condition lasts for a period of time and then the positions and orientations of the LEDs **40** are suddenly reacquired, it follows that the virtual object at rest suddenly jumps to the new position, which is disconcerting for the user. Therefore, even if the positions and orientations of the LEDs **40** can be detected from the AND image again, the virtual object will not be moved to the acquired position on the game image. Instead, follow-up processing will be performed so that the virtual object can move smoothly even when there is some information loss.

FIGS. **14**A and **14**B are diagrams for explaining an algorithm by which the virtual object corresponding to the controller makes a smooth follow-up operation within the game screen. For the sake of convenience, the following description will deal with the case where the virtual object changes in position. The same algorithm can also be applied to a change of orientation.

Suppose that the position estimating unit **104** determines affine transformations, and position parameters P_{i-1}, P_i, and P_{i+1} are derived (the suffix of P indicates the number of the frame of the game screen). Initially, a description will be given of the case where the frame image switches and the position parameter changes from P_i to P_{i+1}.

When the new position parameter (P_{i+1}) is obtained, a position parameter to be reflected on the game screen is given by the following equation:

$$Q_{i+1}=(Q_i+P_{i+1})/2.$$

That is, instead of shifting to the new position parameter P_{i+1} directly, a new position parameter on the game screen is set to the midpoint between the position parameter of the previous frame on the game screen and the new position parameter P_{i+1} of the current frame. It should be appreciated that the position parameter Q_{i+1} need not necessarily be the midpoint between the position parameter Q_i and the position parameter P_{i+1}, but may be a different point that sections the segment between the position parameter Q_i and the position parameter P_{i+1} at A:B.

FIG. **12**B shows an example where the position parameter P_{i+1} cannot be acquired. This algorithm is effective in such cases. Here, the last position parameter is used instead of P_{i+1}:

$$Q_{i+1}=(Q_i+P_i)/2,$$

where P_i is the last position parameter.

When position parameters Q on the game screen are acquired by this algorithm, it is possible to move the virtual object in continuous steps even when the controller **20** makes large movements in space or when it cannot be extracted from AND images. This can avoid situations such as the virtual object suddenly freezing or suddenly moving in the game image, and can achieve smooth follow-up processing for the controller **20**.

Up to this point, the present invention has been described in conjunction with the embodiment thereof. This embodiment is given solely by way of illustration. It will be understood by those skilled in the art that various modifications may be made to combinations of the foregoing components and processes, and all such modifications are also intended to fall within the scope of the present invention.

In the embodiment, the image pickup apparatus **2** captures an image of the controller **20**, and the position and orientation of the controller **20** are estimated from the frame images. The position information and the orientation information are then reflected in the processing of the game application. The LEDs **40** of the controller **20** may be lit in different lighting patterns, for example, depending of the progress of the game application.

Immediately after the user joins the game application, the game apparatus **10** may transmit a control signal to the controller **20** so that the four LEDs **40** are blinked at a predetermined low frequency. The blink instruction unit **106** generates a control signal for instructing a blink pattern of a predetermined frequency to the controller **20**. This low-frequency blink control signal is transmitted from the wireless communication module **108** to the controller **20**. It should be appreciated that if there are a plurality of controllers **20**, the controllers **20** are given respective different blink frequencies.

The controller **20** blinks the LEDs **40** at the instructed low frequency, and the image pickup apparatus **2** captures frame images at capturing cycles of 30 frames/second. From the plurality of frame images, the game apparatus **10** extracts the images of LEDs that are lit on/off at the predetermined cycles. If the game system **1** includes a plurality of controllers **20**, the controllers **20** are given respective different lighting cycles. This makes it possible to check the positions of the controllers **20**, and identify each individual controller **20** separately. This process ideally needs only be performed once after the game application has been joined. In real space, however, controllers **20** may suddenly disappear from the view of the image pickup apparatus **2**. For that reason, the controllers **20** may blink the LEDs **40** at low frequencies set for the respective controllers at predetermined intervals such as every few seconds.

For example, when the four LEDs **40** are blinked at a low frequency, frames in which the LEDs **40** can be captured and frames in which they cannot will occur alternately. If the LEDs **40** are controlled to light on/off at 45 Hz with respect to a capturing cycle of 30 frames/seconds, then the LEDs **40** are alternately captured in two consecutive frames and not in the next two. Since the LEDs **40** are captured in some frame images and not in others, it is possible to acquire position information even if the LEDs **40** are motionless.

Here, the low-frequency lighting refers to the mode of lighting at such frequencies that the lighted LEDs are captured in some frames and not in others, with respect to the capturing cycles. High-frequency lighting, on the other hand, refers to the mode of lighting at such frequencies that the lighted LEDs are always captured in frame images, with reference to the capturing cycles (30 frames/second) of the image pickup apparatus **2**. For example, even when the LEDs **40** are blinked at 1 kHz, the lighted LEDs can be captured in some frames and not in others if the capturing cycle of the image pickup apparatus **2** is extremely short. This makes it possible to acquire position information even if the LEDs **40** are motionless.

The positions and orientations of the LEDs **40** that are blinked at high frequencies are used as an input to the game application. Then, the position information regarding the controller **20**, estimated by the position estimating unit **104**, is sent to the application processing unit **110** in succession and reflected in the processing of the application. User's operation inputs on the arrow key **21** and the like of the controller **20** are also sent to the application processing unit **110** through

the wireless communication module **108**. The application processing unit **110** progresses the game based on the position and orientation information regarding the controller **20** and the operation inputs from the controller **20**, and generates image signals and sound signals that show the results of the processing of the game application.

In a modification, one of the four LEDs **40** can be lit with a blink pattern different from that of the other LEDs **40** so that the particular LED **40** can be identified. For example, when three LEDs are blinked at a high frequency and one LED is blinked at a low frequency, it is possible, for example, to check which is the first LED **40***a* in the frame image.

By detecting the position and orientation of the controller **20** in real space and reflecting them in the processing of a game application, it is possible to realize new types of game applications. Take a tennis game, for example. The controller **20** can be moved to progress the game, provided that the height of the controller **20** in a frame image represents the height of the point where a tennis ball is hit, the direction of the controller **20** the direction of the hit ball, and the moving speed of the controller **20** the power to hit the ball. Since these motions are similar to those of swinging a real racket, it is possible to give the user a sensory experience similar to actually playing tennis. In this case, since the buttons and keys of the controller **20** can also be used as game inputs, it is possible to provide sensuously innovative ways for a user to make game inputs while maintaining conventional game operation inputs. In this way, the LEDs provided as indicators on the controller **20** can be fully utilized to further enhance the variety of game applications available.

For example, the power to hit a ball may be determined by button operations on the controller **20**. The conventional type of button operations and the innovative ways of game inputs can be combined to achieve new gameability. For example, it is possible to create a tennis game such that a ball can be tossed up by making a button input while designating the target position for the ball to hit the ground on the opponent side of the court, and a strong service can be made by moving the controller **20**.

Another example of the game application is a motorcycle racing game. The orientation of the controller **20** may be manipulated and utilized as game inputs for controlling a motorcycle. Here, the speed may be determined by the moving speed of the controller **20**, or may be determined by button inputs. As above, the conventional type of button inputs, static inputs made by the position and orientation of the controller **20**, and dynamic inputs based on changes of state, such as the moving speed of the controller **20**, can be used in combination to improve the operability of game applications.

For example, when the controller **20** is about to go out of the capturing range of the image pickup apparatus **2**, the application processing unit **110** may notify the user of the possibility of going out based on the position information on the controller **20**. Moreover, when the controller **20** is about to go out of range, the application processing unit **110** may generate a vibration control signal for making the controller **20** vibrate its vibrator, and transmit it from the wireless communication module **108**. Furthermore, when a virtual object that follows the movement of the controller **20** is displayed on the game image, the application processing unit **110** may notify the user of the possibility of going out of range by moving the virtual object in a manner noticeable to the user. Whether the controller is about to go out or not may be determined, for example, based on position in frame images. The notification processing may be performed when the position of the controller **20** is estimated to be close to the edges of the frame image.

The features of the invention disclosed in the embodiment may be defined by the following items:

(Item 1)

An image processing apparatus which acquires a position of an illuminator image from a frame image input thereto, comprising:

a differential image generating unit which generates a differential image between a previous frame image and a current frame image;

a binary image generating unit which binarizes the current frame image with a threshold, thereby generating a binary image;

a logic operation unit which logically operates on the differential image and the binary image to generate a logic operation image;

an extraction unit which extracts an illuminator image from the logic operation image; and

a position acquisition unit which acquires the position of the illuminator image in the frame image.

(Item 2)

The image processing apparatus according to item 1, wherein the logic operation unit generates the logic operation image by performing an AND operation between pixel values of the differential image and pixel values of the binary image pixel by pixel.

(Item 3)

The image processing apparatus according to item 1 or 2, wherein the extraction unit recognizes a two-dimensional pattern to be formed by a plurality of illuminators in advance, and uses the two-dimensional pattern to extract the illuminator image.

(Item 4)

The image processing apparatus according to any one of items 1 to 3, wherein the position acquisition unit processes the position of an illuminator image acquired currently as an error if the amount of change between the position of an illuminator image acquired previously and the position of the illuminator image acquired currently exceeds a predetermined value.

(Item 5)

The image processing apparatus according to item 4, wherein the position acquisition unit counts the number of errors occurring in succession, and processes the position of an acquired illuminator image as normal or correct one if the count reaches a predetermined value.

What is claimed is:

1. A game controller capable of communication with a game apparatus, the game apparatus including an imaging device, the game controller comprising:

a wireless communication module configured to transmit a user's operation inputs to the game apparatus input via a plurality of input units provided on a top or rear of a case;

a light-emitting element provided on the rear of the case; and

a processing unit configured to cause the light-emitting element to emit light so as to allow the user to identify the game controller, wherein the processing unit includes a PWM control unit that operates to light the light-emitting element,

wherein the light-emitting element caused by the processing unit to emit light is imaged by the imaging device and used by the imaging device to detect a position of the game controller.

2. The game controller according to claim **1**, wherein the light-emitting element is provided at least at a center of the rear of the case.

3. The game controller according to claim 1, wherein the processing unit causes the light-emitting element to emit light in response to a control signal received from the game apparatus to control lighting of the light-emitting element.

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